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SUSY (s)lepton flavour studies with ATLAS

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Abstract
This report presents studies made to understand the capability to discover and measure properties of supersymmetric particles with ATLAS detector at Large Hadron Collider. It is focused on signatures with sleptons and leptons. All the studies are performed within minimal Supergravity framework.

1 Introduction

Minimal Supergravity (mSUGRA) model is described by 5 parameters: the common scalar mass m_0, the common fermion mass $m_{1/2}$, the common trilinear coupling A_0, the ratio of the Higgs vacuum expectation values $\tan\beta$ and the sign of the supersymmetric Higgs mass parameter μ. In mSUGRA model, R-parity is conserved. If supersymmetry (SUSY) should be discovered at Large Hadron Collider (LHC) it will be vital to measure properties of new particles. Section 2 describes main features of sleptons, Monte Carlo studies of sleptons' masses and spin measurements and study of slepton non-universality. Section 3 considers conclusions.

2 Leptonic signatures

Sleptons ($\tilde{l} = \tilde{e}, \tilde{\mu}, \tilde{\tau}$) are spin zero superpartners of leptons. Left handed sleptons $\tilde{l}_L$ are heavier than right handed sleptons $\tilde{l}_R$ (see Ref. [1]). Mixing between left and right stau slepton is not negligible and mass eigenstates $\tilde{\tau}_{1,2}$ are a mixture of left and right stau slepton. Sleptons are produced directly in pairs $\tilde{l}^+\tilde{l}^-$ or indirectly from decays of heavier charginos and neutralinos (typical mode $\tilde{\chi}^0_2 \rightarrow \tilde{l}_R l$). They can decay to kinematically open gauginos: $\tilde{l}_R \rightarrow l\,\tilde{\chi}^0_1$, $\tilde{l}_L \rightarrow l\,\tilde{\chi}^0_1$, $\tilde{l}_L \rightarrow l\,\tilde{\chi}^0_2$, $\tilde{l}_L \rightarrow \nu\,\tilde{\chi}^\pm_1$.

At the end of every SUSY decay chain is undetectable lightest neutralino $\tilde{\chi}^0_1$ and kinematic end-points in the invariant mass distributions are measured rather than the mass peaks. Kinematic end-points are the function of SUSY masses which can be extracted from the set of endpoint measurements. Fast simulation studies (see Refs. [2, 3]) of left squark cascade decay $\tilde{q}_L \rightarrow \tilde{\chi}^0_2 q \rightarrow \tilde{l}^\pm_R l^\mp q \rightarrow l^+ l^- q\ \tilde{\chi}^0_1$ $(l = e, \mu)$ for the SPS1a mSUGRA point ($m_0 = 100$ GeV, $m_{1/2} = 250$ GeV, $A_0 = -100$ GeV, $tan\beta = 10$, $sgn\mu = +$) were perfomed. Events with two same flavour and opposite sign (SFOS) leptons, at least 4 jets with $p_T > 150, 100, 50, 50$ GeV , and effective mass $M_{eff} = \Sigma^4_{i=1} p_T(jet) + E^{miss}_T > 600$ GeV and missing transverse energy $E^{miss}_T > max(100\,GeV,\ 0.2 M_{eff})$ were selected. Flavour subtraction $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ was applied. After the event selection, Standard Model (SM) background becomes negligible and significant part of SUSY background is removed. Few kinematic endpoints (see Ref. [2]) were reconstructed and fitted: the maximum of the distribution of the dilepton invariant mass M^{max}_{ll} , the maximum and the minimum of the distribution of the $M(llq)$ invariant mass M^{max}_{llq} and M^{min}_{llq} , the maximum of the distribution of the lower of the two l^+q, l^-q invariant masses $(M^{low}_{lq})^{max}$ and the maximum of the distribution of the higher of the two l^+q, l^-q invariant masses $(M^{high}_{lq})^{max}$. From this set of endpoint measurements and by taking into account statistical fit error and systematic error on the energy scale (1% for jets and 0.1% for leptons), SUSY masses $m(\tilde{q}_L) = 540$ GeV, $m(\tilde{\chi}^0_2) = 177$ GeV, $m(\tilde{l}_R) = 143$ GeV and $m(\tilde{\chi}^0_1) = 96$ GeV were extracted with a 6 GeV resolution for squarks and 4 GeV for non-squarks ($L = 300$ fb^{-1}).

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Few experimentally challenging points in the mSUGRA parametre space constrained by the latest experimental data (see Ref. [4]) were recently selected and studied by using full Geant4 simulation. Preliminary full simulation studies of left squark cascade decay for the bulk point, the coannihilation point and the focus point are reported (see Refs. [5, 6]). Events with two SFOS leptons are selected and flavour subtraction $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ was applied. The bulk point ($m_0 = 100$ GeV, $m_{1/2} = 300$ GeV, $A_0 = -300$ GeV, $tan\beta = 6$, $sgn\mu = +$) is a typical mSUGRA point where easy SUSY discovery is expected. The endpoints M_{ll}^{max}, M_{llq}^{max}, M_{llq}^{min}, $(M_{lq}^{high})^{max}$ and $(M_{lq}^{low})^{max}$ were reconstructed for integrated luminosity $L = 5$ fb^{-1}. The coannihilation point ($m_0 = 70$ GeV, $m_{1/2} = 350$ GeV, $A_0 = 0$ GeV, $tan\beta = 10$, $sgn\mu = +$) is challenging due to the soft leptons present in the final state. The decay of the second lightest neutralino to both left and right sleptons is open: $\tilde{\chi}_2^0 \to \tilde{l}_{L,R}l$. The endpoints M_{ll}^{max}, M_{llq}^{max}, $(M_{lq}^{high})^{max}$ and $(M_{lq}^{low})^{max}$ were reconstructed for integrated luminosity $L = 20$ fb^{-1}. The focus point ($m_0 = 3550$ GeV, $m_{1/2} = 300$ GeV, $A_0 = 0$ GeV, $tan\beta = 10$, $sgn\mu = +$) predicts multi-TeV squark and slepton masses. Neutralinos decay directly to leptons: $\tilde{\chi}_3^0 \to l^+ l^- \tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \to l^+ l^- \tilde{\chi}_1^0$ and dilepton endpoints M_{ll}^{max} were reconstructed for $L = 7\ fb^{-1}$. All reconstructed enpoints are at the expected positions.

In the case of direct slepton production where both sleptons decay to lepton and the first lightest neutralino $\tilde{l}_L\tilde{l}_L/\tilde{l}_R\tilde{l}_R \to l^+ l^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$, there are no endpoints in the invariant mass distributions because of two missing final state particles. It is possible to estimate slepton mass by using variable stransverse mass $M_{T2} = min_{E_T^{miss} = E_{T1}^{miss} + E_{T2}^{miss}} \left\{ max \left\{ m_T^2(p_T^{l1}, E_{T1}^{miss}), m_T^2(p_T^{l2}, E_{T2}^{miss}) \right\} \right\}$ (see Ref. [7]). The endpoint of the stransverse mass distribution is a function of mass difference between slepton and the first lightest neutralino $\tilde{\chi}_1^0$. In the case of mSUGRA point SPS1a, fast simulation studies (see Ref. [3]) show that by using stransverse mass left slepton mass $m(\tilde{l}_L) = 202$ GeV can be estimated with the resolution of 4 GeV ($L = 100$ fb^{-1}).

Left squark cascade decay $\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{l}_{L,R}^\pm l^{near(\mp)} q \to l^{far(\pm)} l^{near(\mp)} q\ \tilde{\chi}_1^0$ is very convenient for the supersymmetric particles' spin measurement (see Ref. [8]). Due to slepton and squark spin-0 and neutralino $\tilde{\chi}_2^0$ spin-1/2, invariant mass of quark and first emitted ('near') lepton $M(ql^{near(\pm)})$ is charge asymmetric. Asymmetry is defined as $A = (s^+ - s^-)/(s^+ + s^-)$, $s^\pm = (d\sigma)(dM(ql^{near(\pm)}))$. Asymmetry measurements are diluted by the fact that it is usually not possible to distinguish the first emitted ('near') from the second emitted ('far') lepton. Also, squark and antisquark have opposite asymmetries and are experimentally indistinguishable, but LHC is proton-proton collider and more squarks than antisquarks will be produced. Fast simulation studies of few points in the mSUGRA space (see Refs. [8, 9]) show asymmetry distributions not consistent with zero, which is the direct proof of the neutralino spin-1/2 and slepton spin-0. In the case of point SPS1a, non-zero asymmetry may be observed with 30 fb^{-1}.

For some of the points in mSUGRA space , mixing between left and right smuons is not negligible. Left-right mixing affects decay branching ratios $\tilde{\chi}_2^0 \to \tilde{l}_R l$ and charge asymmetry of invaariant mass distributions from left squark cascade decay. For the point SPS1a with modified $tan(\beta) = 20$, fast simulation studies (see Ref [9]) show that different decay branching ratios for selectrons and smuons can be detected at LHC for 300 fb^{-1}.

3 Conclusions

Fast simulation studies show that SUSY masses can be extracted by using kinematic endpoints and stransverse mass. Preliminary full simulation analysis show that large number of mass relations can be measured for leptonic signatures with few fb^{-1} in different mSUGRA regions. What is still needed to be studied more carefully are: acceptances and efficiencies for electrons and muons, callibration, trigger, optimization of cuts against SM background and fit to distributions. The asymmetry distributions are consistent with neutralino spin-1/2 and slepton spin-0. Different branching ratios for selectron and smuon, caused by smuon left-right mixing, can be detected at ATLAS.

References

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